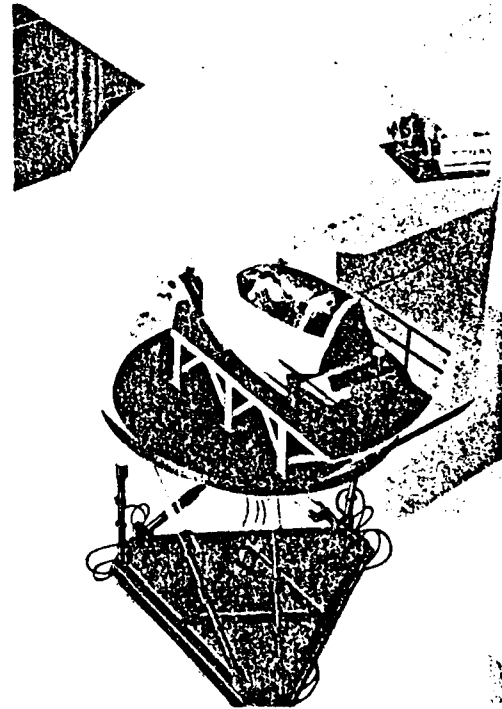
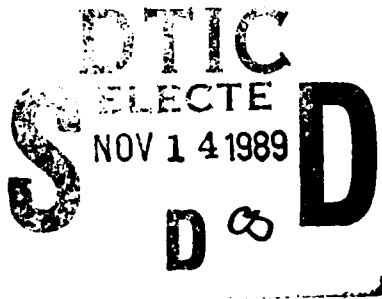


# AIAA FLIGHT SIMULATION TECHNOLOGIES CONFERENCE AND EXHIBIT

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SUMMARY OF PROCEEDINGS OF THE FIRST MEETING OF  
THE NASA AMES SIMULATOR SICKNESS STEERING COMMITTEE

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Abstract

A program of research to investigate simulator induced sickness has recently been initiated under the sponsorship of NASA Ames Research Center at the request of the U.S. Army. A major goal of the program is to coordinate the diverse efforts that have been made by various branches of the Armed Forces to investigate and eventually eliminate the problem of simulator sickness. As part of this program, a Simulator Sickness Steering Committee has been assembled, comprised of eighteen representatives from the Army, Air Force, Navy, NASA, NATO, academia and industry. The proceedings of the first meeting of the NASA Ames Simulator Sickness Steering Committee will be summarized and discussed. (TS) ←

Background

This paper summarizes the first meeting of the NASA Ames Simulator Sickness Steering Committee, held at NASA Ames Research Center on September 27-29, 1988. The major objectives of the meeting were to: 1) provide a general overview of the topic through the presentation of position statements by committee members; 2) achieve a consensus on the implications, causes, and recommended approaches to finding solutions; and 3) develop a working plan for future meetings and activities of the Steering Committee.

The NASA Ames Simulator Sickness Steering Committee was conceived by Anthony Cook, NASA Ames Flight Systems and Simulation Research Division, to provide a common ground for representatives of the U.S.

Armed Forces, NASA, and NATO to exchange information and to promote a better understanding of the simulator sickness syndrome. The objectives of the Steering Committee are to:

(1) facilitate the exchange of information about simulator sickness among the U.S. Armed Forces, NATO, and other organizations;

(2) recommend standardized and innovative methods for assessing the incidence and severity of simulator sickness;

(3) identify and assign priorities to research issues;

(4) encourage the development of simulation engineering design criteria to reduce the problem;

(5) foster the development of guidelines for simulator usage, calibration, and maintenance to reduce the problem;

(6) identify and promote other approaches to understanding and controlling simulator sickness.

The Steering Committee members are identified in Table 1. The members were selected to represent NASA, the three major branches to the Armed Forces, NATO, industry, and academia. In addition, members were selected to provide representation from a variety of disciplines, including engineering, physiology, psychology, and medicine. Individually, committee members possess a

broad range of expertise in flight simulation, including training, design, acquisition, research and development, and the psychological and physiological processes involved in motion, space, and simulator sickness.

### Simulator Sickness

#### Definition

A common definition of simulator sickness, although not necessarily endorsed by all members of the Committee, is as follows: Simulator sickness refers to the constellation of signs and symptoms of motion sickness and related perceptual after-effects that occurs in ground-based vehicular simulators. The simulator sickness syndrome is characterized by adverse symptomatology experienced either during or after exposure to simulated motion scenarios that would not produce sickness in the actual vehicle. Common symptoms are nausea, general discomfort, stomach awareness, and fatigue. Commonly observed signs include pallor, sweating, salivation, and postural instability. In rare cases, severe nausea, vomiting, visual flashbacks or delayed-onset of symptoms may occur.

Differing opinions concerning the prevalence and the indices of simulator sickness were reflected throughout the Steering Committee's discussions. For example, there was active

Activity Dates	
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A-1	21

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TABLE 1  
MEMBERS OF THE NASA AMES SIMULATOR SICKNESS STEERING COMMITTEE

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Anthony M. Cook (Convener)	NASA Ames Research Center
Michael E. McCauley (Chair)	Monterey Technologies, Inc.
Alan J. Benson	RAF Institute of Aviation Medicine
Richard S. Bray	NASA Ames Research Center
Frank M. Cardullo	State University of New York
Walter S. Chambers	Naval Training Systems Center
Malcolm M. Cohen	NASA Ames Research Center
Lawrence H. Frank	Pacific Missile Test Center
Hal Geltmacher	Air Force Human Resources Laboratory
Daniel W. Gower, Jr.	U.S. Army Aeromedical Research Laboratory
Fred E. Guedry, Jr.	Naval Aerospace Medical Research Laboratory
Robert S. Kennedy	Essex Corporation
L. Matthew Landry, Jr.	McDonnell Douglas Helicopter Company
Michael G. Lilienthal	Naval Training Systems Center
Grant B. McNaughton	March AFB
Kenneth E. Money	Defence and Civil Institute of Environmental Medicine
John B. Sinacori	John B. Sinacori Associates
James W. Voorhees	U.S. Army Crew Station Research and Development Branch

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discussion among the Committee members as to whether vision-related symptoms, such as headache, eyestrain, and difficulty focusing, should be included in the definition of simulation sickness. This category of symptoms, sometimes called asthenopia, is not common in other forms of motion sickness. Anomalies in the simulator visual system are believed to be responsible for asthenopia. One argument is to include this cluster of symptoms, in which case the term "simulator induced syndrome" might be more appropriate than "simulator sickness." The other argument is to exclude asthenopia and reserve the term "simulator sickness" strictly for the motion sickness-like symptoms that sometimes result from exposure to simulation. Further discussion is needed to resolve this issue.

Flashbacks, characterized by apparent motion or rotation of the visual field, have been reported infrequently, sometimes many hours after the simulator exposure.<sup>1</sup> This type of symptom is rare and not widely documented, but remains a concern due to the presumed relevance for the safety and health of the affected aviator.

### Brief History

Reports of motion sickness-like symptoms in ground-based flight trainers were flight documented in the U.S. Navy's 2-FH-2 Hovering and Autorotation Trainer more than 30 years ago.<sup>2</sup> Little

research activity was directed toward this issue in the next 20 years. Since the late 1970's, many attempts have been made to determine the extent of the problem, identify the causal factors, and provide guidelines for its alleviation.<sup>3,4,5</sup>

More recently, experimental efforts have attempted to identify characteristics of the simulator, the simulated flight scenario, and the simulator user which may lead to the occurrence of simulator sickness.<sup>6,7,8</sup> The issues involved in understanding and alleviating simulator sickness are relevant to the design and use of other systems which rely on the use of virtual imagery to represent orientation and motion through space, such as helmet mounted displays, advanced cockpits and crew stations, and remotely piloted vehicles.

## Problem Identification

Several areas of concern were identified by the committee as being negatively influenced by the occurrence of simulator sickness:

### (1) Safety and Health.

There are potentially profound safety and health implications for users who experience either prolonged or delayed-onset symptoms following use of the simulator. Although members of the committee agreed that reports of long-term aftereffects of simulation are generally anecdotal and uncommon, the obvious implications for safety of flight require that the phenomena be assessed more thoroughly. The concern is that simulator sickness, or adaptation to the circumstances that produced the sickness, may increase the likelihood of a subsequent flight accident. A related concern is whether the simulator user is at risk while driving an automobile or engaged in similar tasks. Simulator manufacturers and simulation facility managers may be concerned about liability issues related to the frequency, nature, strength, and duration of simulator aftereffects. Very little information is available on prolonged or delayed-onset symptoms or long term simulator aftereffects. <sup>1</sup>

### (2) Training

Effectiveness. Negative training could result from simulator sickness. Strategies used by individuals to minimize the occurrence of sickness in the simulator

(e.g., limiting head movements) could result in poor transfer of training to the aircraft. Also, user acceptance of a training simulator may suffer when a high incidence of sickness is associated with its use.

### (3) Validity of R&D Data.

Research and engineering design data could be contaminated if simulator pilots are experiencing adverse symptoms. However, committee members familiar with the use of simulators as engineering design tools report infrequent problems with simulator sickness. Reports of sickness in research simulators (in studies unrelated to simulator sickness) have been rare.

### (4) Scheduling and Utilization.

Establishing schedules for training flights and simulator sessions is complicated by simulator sickness. Pilots who suffer from severe symptoms may need to be removed from flight duties temporarily. Their sudden unavailability detracts from flight training schedules and, perhaps, on general flight readiness. Temporary grounding policies have been adopted as a precautionary measure following simulated flights at some military training locations. NAS Miramar, for example, has adopted a mandatory 12-hour grounding period following an initial training session in the F-14 simulator, and a 2-hour minimum following all subsequent simulator training sessions. The U.S. Army has,

in most cases adopted a 6-hr hour "waiting period" between simulator usage and actual flight.

The concerns listed and discussed above are speculative. They provide a rationale for further investigation of the simulator sickness phenomenon, which the Steering Committee views as an unwanted side effect of simulation. The Steering Committee members are unanimously strong advocates of simulation for training and research.

### Incidence and Symptomatology

Although reports of simulator sickness have been documented with increasing frequency in recent years, some disagreement remains about the operational significance of the problem. Some members of the Steering Committee, for example, felt that strong evidence for simulator sickness requires comparison to the incidence of sickness occurring in the actual aircraft.

Committee members from the U.S. Navy and Army, as well as the Royal Air Force of the United Kingdom, described their efforts to quantify the occurrence of simulator sickness in their training facilities. In general, their approach has been to conduct on-site evaluations to assess the well-being of pilots before and after using the simulator in representative scenarios. These assessments generally have relied upon the use of some variant of the Motion Sickness Questionnaire (MSQ) developed more than 20 years ago.<sup>9</sup> The MSQ is

essentially a checklist of 20 to 30 "major" and "minor" symptoms of conventional motion sickness. A single score is derived from the specific symptoms selected and their severity. Tests of postural stability also are typically used in assessing simulator sickness.<sup>10</sup>

The use of the MSQ and tests of postural equilibrium are employed in a pre-test, post-test fashion to assess changes in pilots' well-being following simulator training sessions. Representatives of the U.S. Navy stated that the use of pre- and post-measures may contribute to an underestimate of the incidence because some pilots may experience symptoms in the simulator and subsequently, through adaptation, recover before the end of the simulated flight.

The U.S. Navy has conducted simulator site surveys for over five years, and has generated a database of over 2000 observations at 10 simulator sites.<sup>11</sup> Their results reveal incidence rates (based on the existence of at least one symptom) ranging from 10% in the F-14 Weapon System Trainer at NAS Miramar to 60% in the SH-3 Operational Field Trainer at NAS Jacksonville. The U.S. Army has recently begun to assess the extent of the simulator sickness problem in their trainers, and has reported a 44% incidence rate in the AH-64 trainer at Ft. Rucker.<sup>12</sup> As a result of their investigations, the Navy has recently produced a set of guidelines in the form of a "field manual" for simulator instructors and pilots to

attempt to minimize occurrences of the problem.

Steering Committee members representing the U.S. Air Force reported that they have had few significant indications of simulator sickness problems, with the possible exception of the Simulator for Air-to-Air Combat (SAAC) at Luke AFB. It was reported that an estimated 20%-30% of pilots using the SAAC voluntarily report some type of adverse symptom, although no official statistics are compiled. In approximately 5% of exposures, the effects are sufficient to warrant temporary interruption of the training session. There is no policy of temporary grounding at Luke following use of the SAAC. In general, the Air Force reports no significant problem or concern with simulator sickness at their simulator facilities, although no systematic analysis of the issue has been published.

Several members of the Steering Committee suggested that the incidence of simulator sickness reported by the Army and Navy may be overestimated because a "case" is claimed even when only one minor symptom, such as sweating or fatigue, is reported. Whether such minor symptoms are valid indicators of simulator sickness was questioned. No consensus was reached by the Steering Committee as to the number or type of symptoms required to indicate a case of simulator sickness. Likewise, there was no general agreement on the severity of symptoms required to prompt concern for flight safety or operational readiness.

Although sweating and fatigue are common in motion sickness, they may occur for other reasons. Pilots routinely sweat while engaged in intense simulation sessions like air-to-air combat or night carrier landings, for example, although the sweating only occasionally appears to be related to sickness. Furthermore, the occurrence of fatigue may be related to situational characteristics of the simulation, such as excessive physical or cognitive effort, and should be distinguished from the sleepiness ("sopite syndrome") that is sometimes characteristic of motion sickness. 13

The definition of symptom prevalence used to indicate an overall incidence of simulator sickness at a specific simulator site is still an issue. The practice of using one "minor" symptom to identify a case of sickness was viewed by some Steering Committee members as producing an overestimate of the simulator sickness problem at Army and Navy facilities. On the other hand, the Air Force may be underestimating the problem because pilots may be unwilling to voluntarily report adverse symptoms.

#### Comparisons Between Simulators and Aircraft

The Steering Committee strongly recommended that future analyses of simulator sickness incidence include comparisons of the symptoms experienced in actual and simulated flight. Simulator surveys to date have not compared simulator and



aircraft data for either of the common measures of simulator sickness, self-report (MSQ symptom ratings) or postural stability measurement.

Using air sickness data as a baseline will enable a more accurate assessment of the extent of the simulator sickness problem. This concept is inherent in the common definition of simulator sickness as a constellation of signs and symptoms that occurs in the simulator but not in actual flight. The Army and Navy have recently modified their simulator sickness questionnaires to determine whether maneuvers performed in the simulator result in adverse symptoms that would normally not be expected in the aircraft.

#### Conflict Theory

The commonly accepted theory of motion sickness is the sensory conflict theory, sometimes known as "neural conflict" or "neural mismatch." While these terms usually are considered to be synonymous, some Steering Committee members make a distinction between them. For example, it was suggested that the terms "sensory" and "neural" imply different levels of human processing of spatial information. Both are based on a temporal and/or spatial mismatch of information about one's orientation or motion through space, but sensory conflict implies that the mismatch occurs at the level of the proprioceptive end organs, while neural conflict implies a discrepancy between actual

and expected information. Sensory conflict occurs at the receptors that directly receive information about orientation from the environment (primarily the visual and vestibular receptors). Neural conflict refers to a mismatch between the currently experienced pattern of proprioceptive stimulation, and a neural store of previously experienced patterns.

Both versions of the conflict theory have some strengths, but share a common weakness -- the lack of a quantifiable measure of conflict. Steering committee member John B. Sinacori suggested an initial approach to quantifying the physical conflict between the motion implied by the simulator visual system and motion delivered by the motion base. Briefly stated, a measure of conflict present in a simulated flight scenario could be defined as the integrated absolute value of the difference between the angular velocity and specific force vectors as calculated by the host computer and as produced by the visual and motion-base systems. In other words, the physical conflict would be calculated as the difference between the intended aircraft motion (portrayed by the visual system) and the actual motion produced by the motion base. Mr. Sinacori suggested this approach as a first attempt at the quantification of conflict theory, a process strongly recommended by the Steering Committee.

## Consensus Items

The following list of consensus items is derived from highlights of the presentations given at the meeting as summarized by Dr. Fred E. Guedry, Jr.:

(1) There is a simulator sickness problem. Nausea, however, is not perceived as being as critical a problem as potential long term aftereffects.

(2) Several implications of simulator sickness or simulator aftereffects are important:

- o Increased probability of in-flight accidents.
- o Negative transfer of training.
- o Increased risk of post exposure personal injury.
- o Decreased user acceptance of training simulators.
- o Compromised validity of data from research simulators.

(3) Temporal effects of perceptual adaptation are important. There is a need for more information about the rate of adaptation to the simulator and the rate of readaptation to the aircraft.

(4) The physical features that provoke sickness need to be clearly identified.

(5) An experimental approach is necessary to identify contributing factors.

(6) Quantification of the conflict theory is needed.

(7) Prediction of individual differences in susceptibility is recommended.

## Directions for Future Work

In addition to the consensus items identified above, several suggestions were contributed to provide direction for future investigation of the simulator sickness problem. These are summarized briefly as follows:

(1) In conducting assessments of the incidence of simulator sickness at a particular facility, or when conducting research on simulator sickness, it is important to provide a sufficient engineering analysis of the simulator being used. This should include a fundamental technical description of the facility, including the motion base, visual displays, and temporal characteristics of both. These descriptions should be standardized to facilitate the pooling of data from different facilities.

(2) There is a need to develop a standardized vocabulary of technical terms relating to simulation and simulator sickness. The multidisciplinary interest in simulator sickness underscores the importance of generating a common language to facilitate accurate communication.

(3) A standardized means of assessing the presence of effects before, during, and

after simulator sessions is needed to support the formation of a global simulator sickness database. This includes the need to develop a reliable means to assess the nature and severity of long-term aftereffects.

(4) Any simulator sickness assessment or analysis needs to be interpreted with respect to what happens in the actual aircraft performing similar maneuvers. By definition, simulator sickness does not exist if pilots become ill in the aircraft in the execution of similar scenarios. A comparison of incidence rates in the simulator and aircraft would provide a more definitive estimate of the extent of the simulator sickness problem.

(5) There is a need to develop more sensitive measures of simulator sickness, particularly with respect to postural equilibrium. The commonly used tests of standing and walking steadiness may be rather insensitive to ataxic side effects as compared to the level of precision available with a force platform or stabilometer. Similarly, the search for reliable physiological indices of sickness should be continued.

(6) Comprehensive descriptions of simulator scenarios are also necessary for adequate definition of the conditions encountered by the pilot. These descriptions, ideally, should include the actual and implied motion characteristics experienced by the simulator pilot during the

scenario.

(7) Individual differences in susceptibility to simulator sickness may be predictable. Areas such as perceptual sensitivity, control strategies, personality and flight experience should be investigated.

(8) A database of engineering and procedural "fixes" that have been useful in alleviating simulator sickness should be developed. For instance, personnel operating the SAAC noted that they had more problems with sickness when there was a great deal of perceived roll in a scenario. After blurring the horizon on the visual display, they noted a subsequent decrease in the occurrence of sickness. These individual "lessons learned" need to be compiled in a single, widely-available database.

(9) Perceptual adaptation occurs with repeated exposures to the simulator, resulting in a reduction of simulator sickness. However, this may be achieved at the cost of readapting to the environment outside the simulator. For example, Gower et al observed a concurrent decrease in postural stability outside the simulator with reduction in symptomatology.<sup>12</sup> Better understanding is needed of the processes of perceptual adaptation related to simulator exposure followed by readaptation to the real world.

(10) The consensus of the committee was that the occurrence of transient adverse symptoms in the

simulator is less a matter of concern than the safety implications of long-term or delayed-onset aftereffects. The investigation of the nature, duration, and causes of aftereffects is a high-priority research issue.

(11) An experimental approach is recommended in addition to continued monitoring (survey) of the incidence of the problem at training simulation facilities. Empirical data are needed to identify the causal factors. Most military flight simulator facilities are devoted to training and are unavailable for experimental studies. Research simulation facilities, such as those at NASA Ames Research Center and the Navy's Visual Technology Research Simulator, represent ideal environments for gaining further understanding of the causal factors.

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